A universal substrate sample fixture for efficient multi-instrument inspection of large, flexible substrates, with absolute position registration support

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A universal substrate sample fixture for efficient multi-instrument inspection of large, flexible substrates, with absolute position registration support

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Abstract
Diagnostic inspection for process optimisation and accelerated lifetime testing occupies a significant fraction of unit cost for both traditional, and emerging printed large-area electronic devices. Much of this testing is time-intensive, involving multiple instruments and expert-driven laboratory analysis, developing and correlating maps of local surface topography parameter variation, functional performance indicators and visual appearance. We present the concept and development of an affordable, universal substrate sample fixture (USSF) to enable large-area topography and functional performance measurements with greater efficiency, autonomy and accuracy of absolute feature registration. The USSF is initially optimised for diagnostic inspection of thin, rigid and flexible, highly-parallel manufactured samples up to 180 mm × 180 mm. The USSF is, therefore, particularly relevant for photovoltaic wafers, injection-moulded or embossed nanostructures, and roll-to-roll printed large-area electronics. The USSF incorporates a universal base plate for permanent installation, kinematic locators and semi-disposable substrate clamps. The USSF will also incorporate calibration artefact holders to encourage routine use of, for example, stage calibration line-scales and areal calibration artefacts. We demonstrate a semi-disposable sample mount designed to transfer an absolute coordinate system with a lateral repeatability of 100 µm between multiple instruments, including via storage and mail transport.

Keywords: sample handling, universal fixture, surface-function correlation, automated diagnostic inspection, metrology for highly-parallel manufacturing, calibration

1. Motivation for development

Solutions for overcoming throughput barriers in large-area, high-resolution inspection of, for example, photovoltaic (PV) wafers or diffractive films require intelligent measurement simplification based on sound *a priori* knowledge of defect classes and feature geometries [1]. This preparatory analysis should be automated and standardised to reduce costs and uncertainty. The MetHPM project [2] includes development of lab tools for sample study for parameterised surface-function correlation, GPS-tolerancing, and inline process control.

Handling and measurement of large, flexible samples introduces challenges not encountered with conventional rigid workpieces. Common functional tests require access to both sides of flexible samples, yet support is required to match the vertical working ranges of optical instruments, and to minimise flutter induced by local airflow. Thin substrates are easily deformed and often lack well-defined edges or features visible by eye. These factors make it challenging to maintain the registration of recorded features or defects from instrument to instrument. Samples may also be environmentally sensitive and require contamination control, especially during storage.

Relevant state of the art in sample manipulation from precision machining [3], silicon wafer processing and medical microscopy must be combined into a simple-to-use and cost-effective solution to encourage its uptake.

Section 2 describes the general USSF concept designed to address these handling challenges. Sections 3 and 4 present implementations for the study of semi-rigid PV wafers and roll-to-roll embossed nanostructures respectively. In section 5 the remaining challenges are considered and the outlook noted.

2. Universal substrate sample fixture (USSF) concept

In the current working concept, the USSF consists of a universal permanent element (PE) (a plate with kinematic locator points), installed on multiple instruments, and multiple classes of sample holder ('semi-disposable element', SDE) that are quickly and repeatably installed onto the PE (see figure 1). The PE would require the development of an adapter plate for each instrument. The specifications of SDE classes would be matched to the needs of the application, as exemplified in the following sections. Reference (datum) markers on each element support a global coordinate system shared across instruments. This simplifies the labelling and documentation of notable features, and improves confidence in feature-finding, especially during rapid process optimisation. The split PE-SDE approach supports rapid sample exchange for higher utilisation of high-capital instruments, sharing of instruments between collaborators, and routine insertion of calibration plates for dark-hours instrument verification.

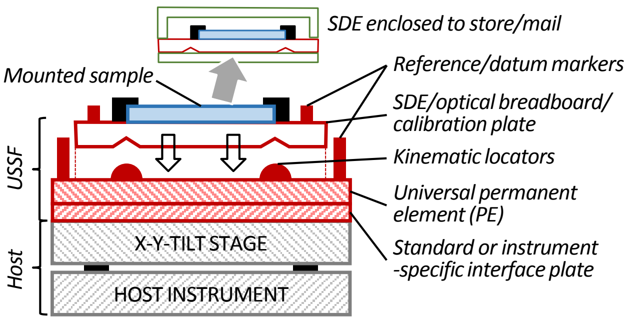

Figure 1. Block diagram of generalised USSF concept (lateral view).

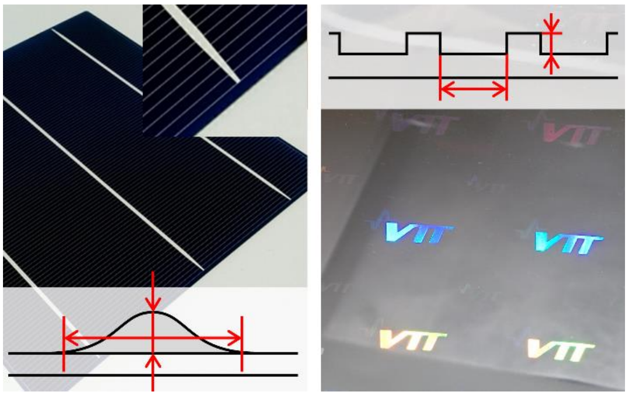

Figure 2. Typical examples of products associated with the two USSF versions described, and relevant geometrical measurements: (left) semi-rigid PV wafers with printed electrodes (courtesy Applied Materials) and (right) cosmetic or functional gratings embossed on thin, polymer web (courtesy VTT).

3. USSF realisation for photovoltaic wafer inspection

Our first example considers periodic extended testing of volume-produced PV wafers. The substrate is locally rigid and flat, but has significant form deviation under self-weight on the 100 mm scale. Printed electrodes have well-defined locations over the wafer, with a low fractional coverage. Electrodes are typically inspected for cross-sectional dimensions, requiring 3D surface topography measurement. Others instruments locally map electronic function, contacting top-side wafer edges.

A prototype USSF is shown in figure 2 with an SDE optimised for a (156×156) mm^2 flat wafer. Since the PV wafer has well-defined edge geometry, it can be repeatably installed against suitable stops. The SDE represents a simplified wafer holder from semiconductor fabrication. Springs and stops constrain lateral motion, leaving the top surface clear to avoid microscope objective collisions. Since many 3D instruments have default $\{XY\}$ translation ranges below (100×100) mm^2, the PE contains kinematic spheres defining five coarse $\{XY\}$ installation positions (figure 3), each with multiple available orientations. In this way, the sample may be rapidly repositioned laterally and/or rotated to bring portions of the wafer into range for automated inspection. The coarse positions of this PE have been optimised for PV inspection (the primary activity), but other SDEs are still supported. Similarly, this wafer-holding SDE can be sent to any partner or instrument with a PE with a matching kinematic sphere grid.

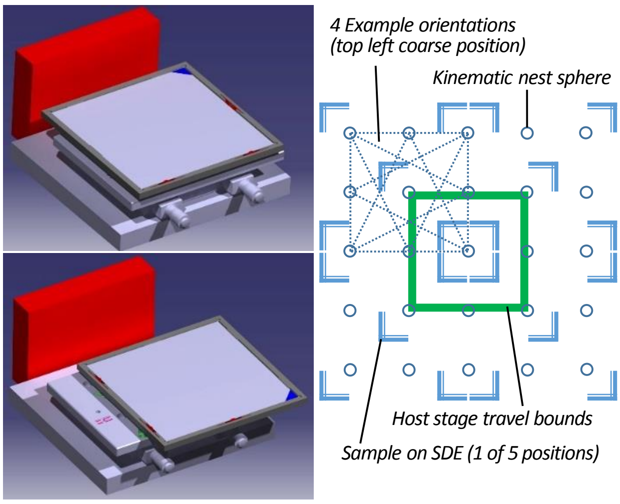

Figure 3. Rendered view of a CAD model of the PV USSF with the sample holder (top left) in the central position and (bottom left) after lateral displacement combined with a 90° clockwise rotation. Various coarse $\{XY\theta_Z\}$ installation positions are summarised (right).

The optimum provision of coarse positions may vary by sample size, functional requirement and sampling strategy [4]. The PE is equipped with tip/tilt adjustment to bring the surface back into the host instrument's axial and tilt range after each change in sample position.

Traceability must underpin the function of the USSF, both for compliance and practical reasons. The USSF will be supplied with a plate containing areal calibration artefacts and optical dimensional standards (figure 4), installed in place of the SDE.

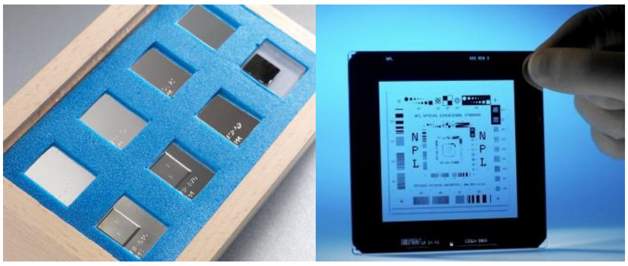

Figure 4. Extra plates will support various artefact types: *e.g.* (left) areal calibration set; (right) optical dimensional standard (NPL examples).

4. USSF realisation for embossed polymer web inspection

A second example of the USSF is being developed for the handling and inspection of flexible roll-to-roll substrates, *e.g.* embossed micro-/nanostructures (figure 2), printed electronics, flexible PV, and barrier coatings [5, 6]. Such substrates may be less than 50 µm thick and suffer from wrinkling, sag and flutter; yet support structures must allow back-side functional tests or transmission-mode optical inspection. Potential mid-process inspection implies contamination control and cleanroom compatibility, yet the SDE must remain disposable enough to allow permanent attachment of a rough-cut sample (by, *e.g.*, pressure-sensitive tape). Flexible, low-cost laser-processing and 3D printing methods are being pursued to obtain the best compromise between alignment uncertainty, compatibility and unit cost. This version contains a central void for unobstructed access to both sides of the sample under test.

5. Outlook

We present a USSF concept to handle and share flexible, planar samples up to (180×180) mm^2, demonstrating how state of the art fixturing from various advanced manufacturing techniques may be combined into a cost-effective lab tool for efficient and traceable process output study. Feedback from industry to optimise lab resources is encouraged. The USSF prototypes will now facilitate multi-site inspection for key test cases demonstrating quantified process improvements based on novel metrology for highly-parallel manufacturing. Planned SDEs for optical coordinate metrology of conventional optics, tessellated machined surfaces [7] and micro-parts will exploit good practice from precision machining fixtures.

Acknowledgement

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